Possible
U.S. Contributions to JET Diagnostics

Presented by

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with input from

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Outline

- **Potential support of the diagnostics for the JET-EP program**
  - For turbulence and transport studies
    - including upgrades in progress
  - For fast-ion physics and alpha-particle measurements
  - Lithium blanket module
- **Summary**

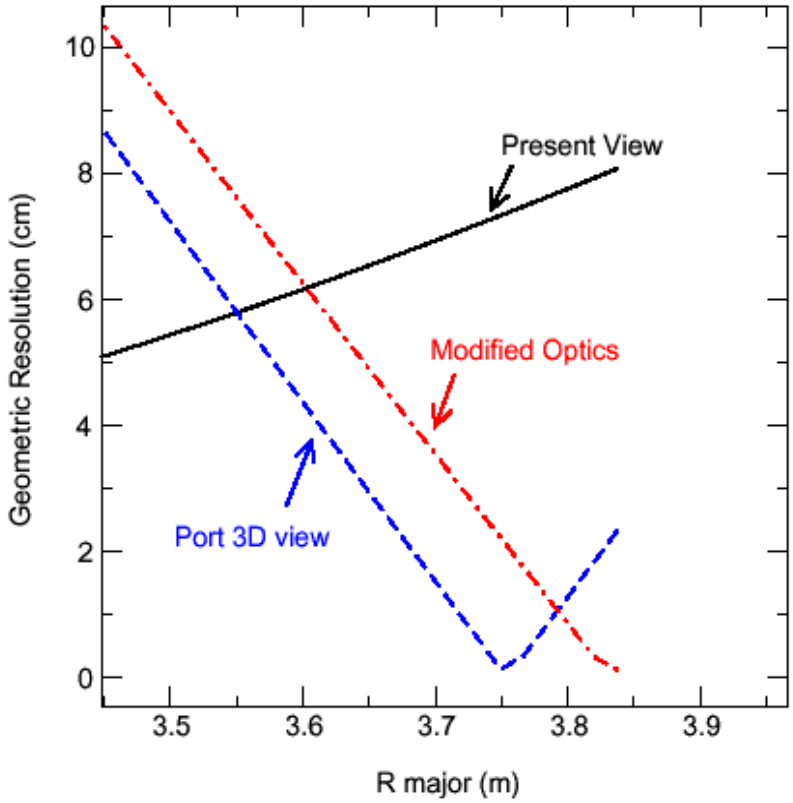
Diagnostics for Transport and Turbulence Studies

Current Status of JET MSE System

- Routinely produces reliable q-profile measurements and plays an important role in Task Force S2 experiments
- Recent observation of region of $j(r) \approx 0$ near the plasma axis ($r/a \leq 0.2$) in discharges with LHCD applied during current ramp (PRL in preparation)
- Near-term Plans for Hardware:
- Energy of PINI 1 of Octant 4 NB injector will be increased to 130 keV during 2001 shutdown
  - Will eliminate contributions to signal from interfering beams, making possible measurements in discharges with any combination of beams
  - Will make edge channels usable by eliminating carbon line interference
- PPPL will supply new interference filters and dichroic prism components needed for higher beam energy

Possible MSE Diagnostic Upgrades for JET-EP

- To measure q and E_r with high sensitivity and good spatial resolution, must have two MSE systems viewing co- and counter- beams.
- Original plan was to implement second MSE viewing proposed Oct. 2 counter-beam.
- Another possibility:
- Opposing view of existing beams (I.e. opposite Doppler shift compared to existing system) from port 3D would have good spatial resolution at edge but would not yield E_r measurement.
- If counter beam were added later to Octant 4 injector, would get q and E_r measurements with good spatial resolution at edge and in core by combining data from both systems.
- Suited to staged approach: add second MSE system for JET-EP and DNB later.



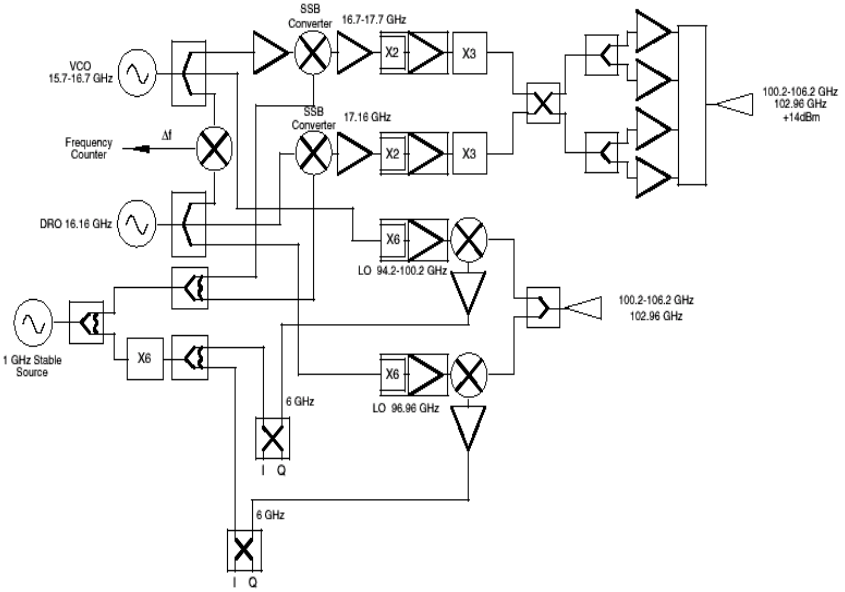
Spatial resolution from Port 3D

Full time evolutions will be possible with beam energy upgrade so consider extending data window beyond present 3 seconds.

Upgrade data acquisition to commercial DSP lock-in amplifier system.

Microwave Correlation Reflectometry for Study of Turbulence

- Reflectometry system will have good time (<1 μs) and spatial (< 1 cm radial) resolutions, and sensitivity to density fluctuations down to 10^{-4}.
- Existing reflectometer has three radial positions; very poor overall transmission and cannot be used above 110 GHz.
- IST (Portugal) responsible for adding two additional correlation channels; US is providing 100 - 106 GHz correlation pair prior to 2002 operation.



Block diagram for correlation pair

Upgrade for EP-program

- Will allow full coverage of plasmas for higher fields
- New port access using limiter tube will give direct sight-line inside vacuum vessel
- Low-loss waveguide will enable use of tunable sources
- System will be built up of several correlation pairs of same type.

JET Pellet Spectrometer

Current Status: Phase 1 Instrument

Stand-alone system -- Operational November 2000

- Single time integrated spectrum per pellet
- Phase 1 results support move to phase 2
- Light levels sufficient for 200ms resolution
- FWHM 4 to 10 nm, 1nm resolution adequate for phase 2, but improved resolution desirable
- Unexpected elevated interline signal level under study

Phase 2 Plans

Phase 2 Instrument – High time resolution system capable of both stand-alone and Integrated CODAS operation
CODAS requirement specification established – January 2001
Instrument checkout will continue at DIIID during JET shutdown
Development of high speed detector and possible improved resolution instrument underway
If approved, install phase 2 system for 2002 JET operations – December 2001

High Resolution Thomson Scattering

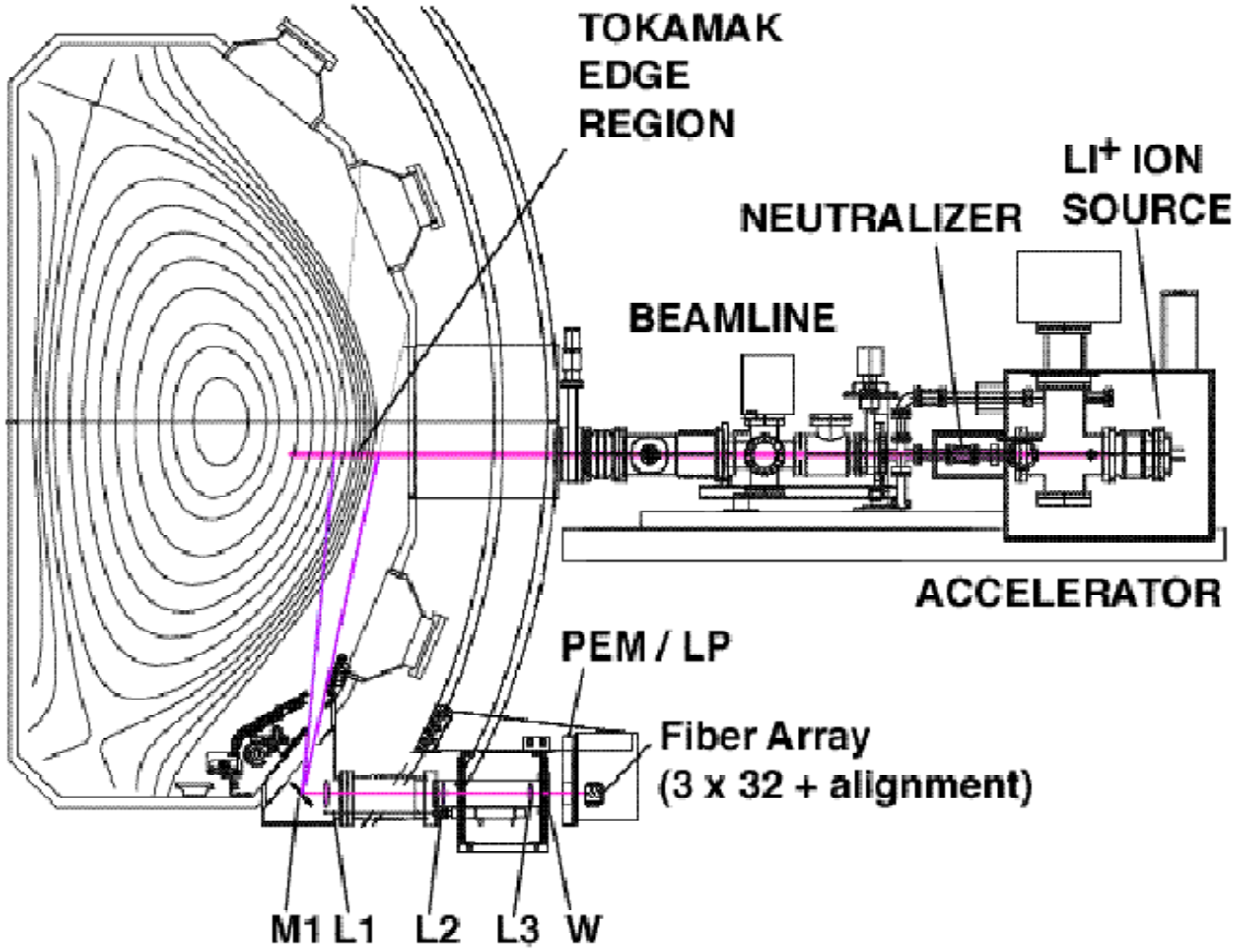
- Scientific rationale:
  - Need improved resolution of gradient zones at ITBs and edge pedestal
  - Relates strongly to JET/DIII-D comparisons

- Collaboration
  - Consulting / Conceptual design
    - Continuation of participation by T. Carlstrom in working group
  - Design and/or Construction of components
    - Polychromators
  - Physics Participation / Exchange

- **Areas of Collaboration**
  - Support diagnostic development
  - Experimental Studies
  - ITBs
  - Pedestal Physics
  - L-H transition, ELMs
  - Edge Stability

Li-Beam Possibility for JET-EP
Li-Beam System on DIII-D

- Li^0 Beam:
  - 30 keV
  - 10-20 mA
  - 1-2 cm dia
  - single species



Polarization Analysis of JET Li-Beam

- **May be feasible; substantial studies will be needed to predict ultimate performance potential.**
- **Possible Points of Cooperation:**
  - Design, development, and implementation of precision polarimetry measurements based on DIII-D experience.
  - Participation in experiments on bootstrap measurement, pedestal stability studies.
  - Advice on high current beam construction and implementation, cooperation on development. Optimization of design for installation, if pursued.
  - Concept exploration/conceptual design for laser assisted measurement.

Edge Density Reflectometry

- **Extensive experience at edge density profile measurements - NSTX, TFTR, PBX-M & DIII-D**
- **Specialize in making edge density profile measurements in or near RF or LH antennas**
- **Provide time evolution of density profiles starting at densities as low as ~1x10^{10} cm^{-3} with sub-millimeter spatial resolution**

- **Proposal for JET-EP**
  - Propose incorporating an Edge Reflectometer System in the JET RF and/or LH antennas
  - ORNL will participate in the design, fabrication & installation of the reflectometer launcher and waveguide system
  - ORNL will build, install & operate the reflectometer system

Other possible diagnostic support for operations and transport studies from the US

- **Design support for magnetic diagnostics**
  - Halo current measurement
  - Analysis of disruptions
- **Charge Exchange Spectroscopy**
  - Ion temperature and rotation
  - Helium diffusion and helium-ash studies
- **Respond to specific requests from EFDA-JET or Association**
- **Support of system software and interface hardware with CODAS**

Diagnostics for fast-ion physics and alpha-particle measurements

New Alfvén Antennas for JET-EP

- **Existing antennas (the 4 Saddle Coils):**

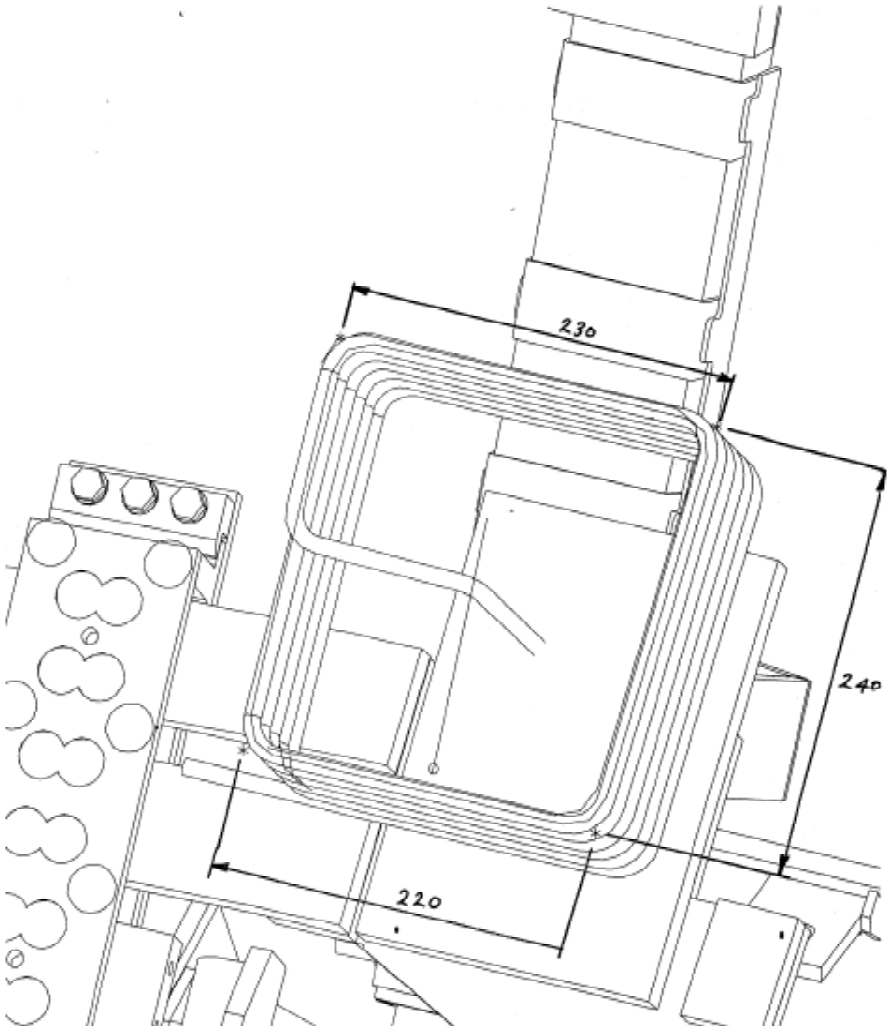
➡ **stable n = 0 - 2 AEs, $|\delta B_\theta/B| \approx 10^{-6}$**

- **Unstable AEs have higher n=6-15**

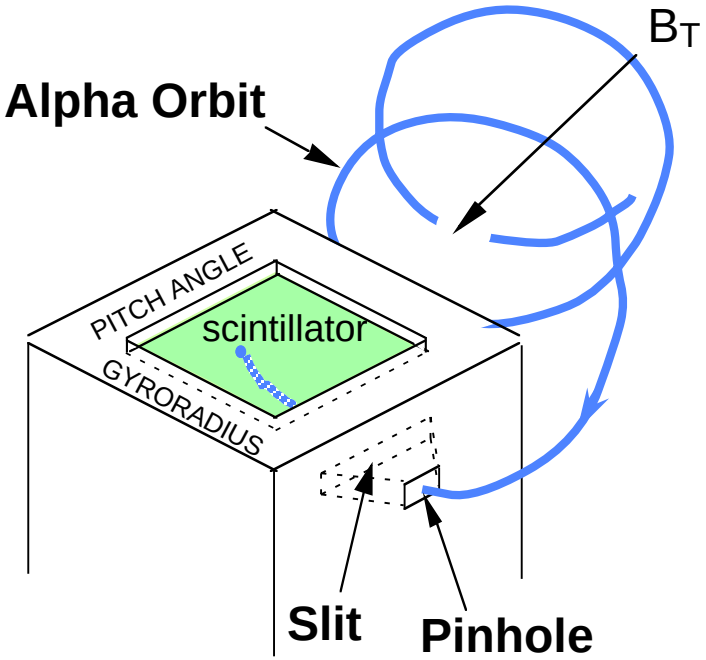
- **New antennas for high-n excitation:**

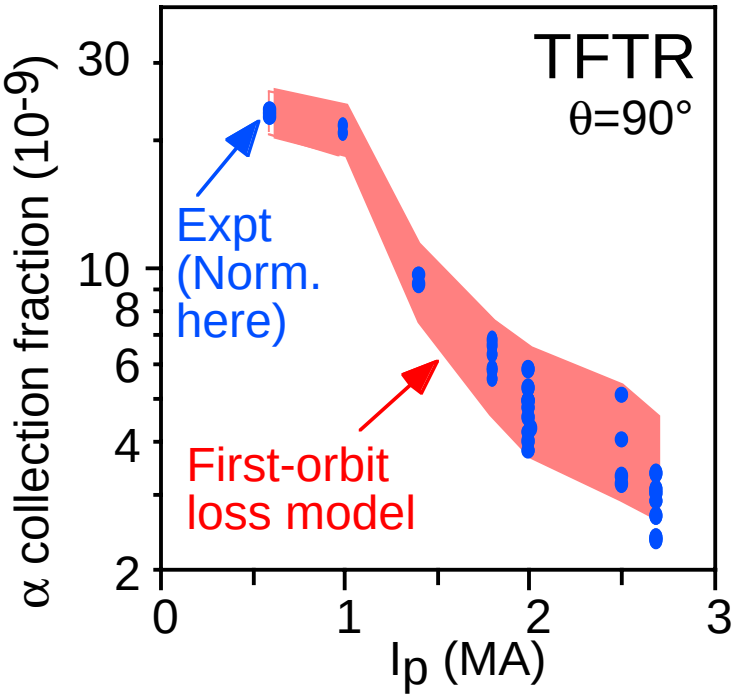
➡ **8 antennas toroidally asymmetric**

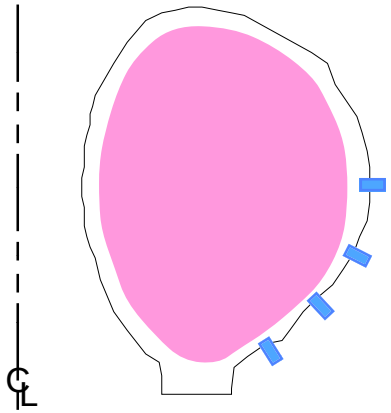
Possible US participation in design and hardware



Versatile "Lost Alpha" diagnostic for JET would give alpha data for wide range of plasmas



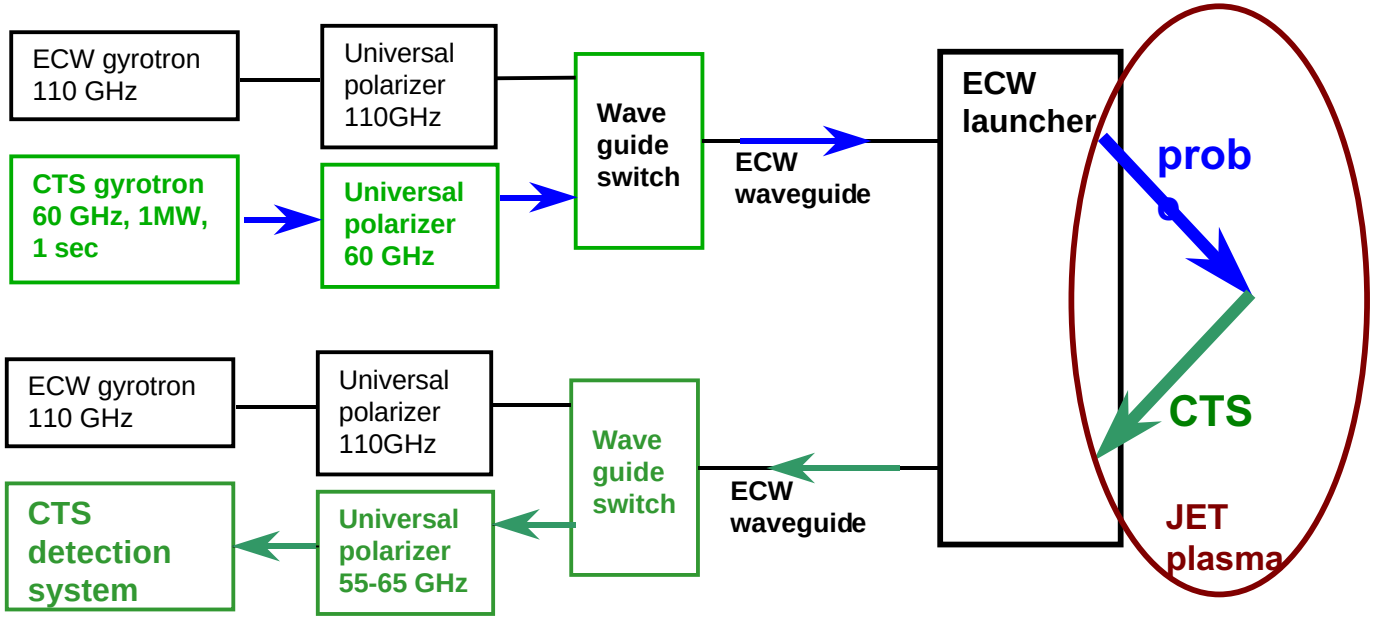




- Use TFTR-style scintillator detectors; could combine with Faraday cup sensors
- Prompt, collisional, & ripple loss MHD, ST, TAE. & ICH interactions
- Measures αs and ICH tail ions

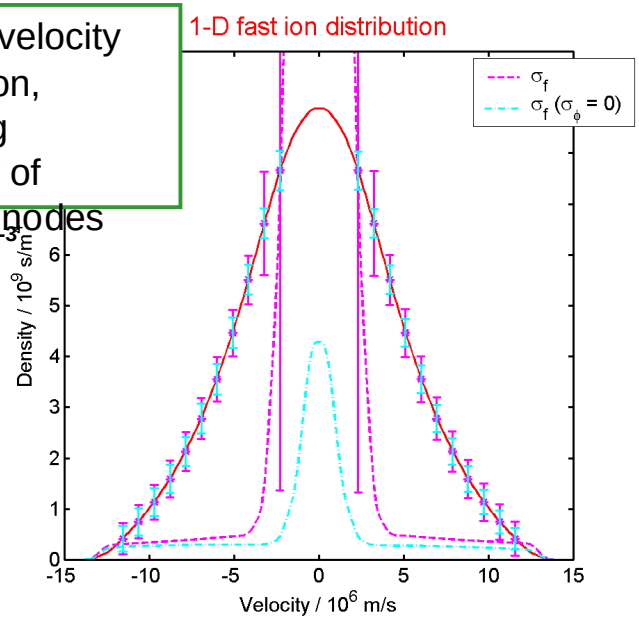
JET Faraday cup

Microwave Fast Ion CTS for JET-EP



Model α velocity distribution, indicating accuracy of resolved nodes

$n_\alpha = 10^{17} m^{-3}$



Diagnostic capability

10 time slices, 100 ms integration:

0.9×10^6 m/s velocity resolution

20 nodes in fusion alpha distribution

Node uncertainty ~ 3×10^8 s/m^4

Radial resolution < 20 cm

Measurements in most of plasma cross section

$v_\perp$ and $v_{||}$ distributions can be resolved

Microwave Fast Ion CTS for JET-EP

- Features
  - 60 GHz, X-mode, large backward scattering angle (>90°)
  - takes advantage of JET-EP ECRH infrastructure
    - engineering support, one of eight unused beam lines

- Advantages
  - 10 - 100 measurements per plasma shot of 10 -100 ms resolution
  - 20 or more point resolution of alpha velocity distribution
  - $v_{\perp}$ and $v_{||}$ velocity distributions resolved
  - 20 cm spatial resolution
  - validated with recent results on TEXTOR

- Two receiver systems with filter banks from TEXTOR for v-par. and v-perp., or for noise subtraction could be available

- Concern: need for 1 MW 60 GHz gyrotron

CO_2 Laser Collective Thomson Scattering Alpha Particle Diagnostic

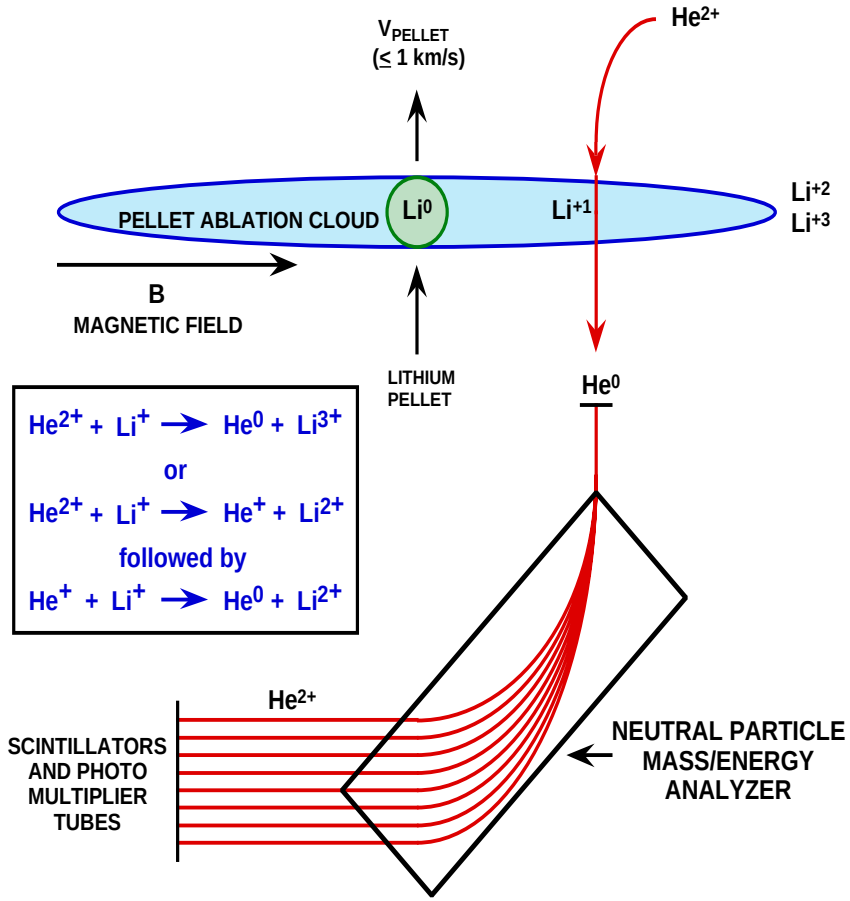
Existing JT-60U/ORNL Diagnostic

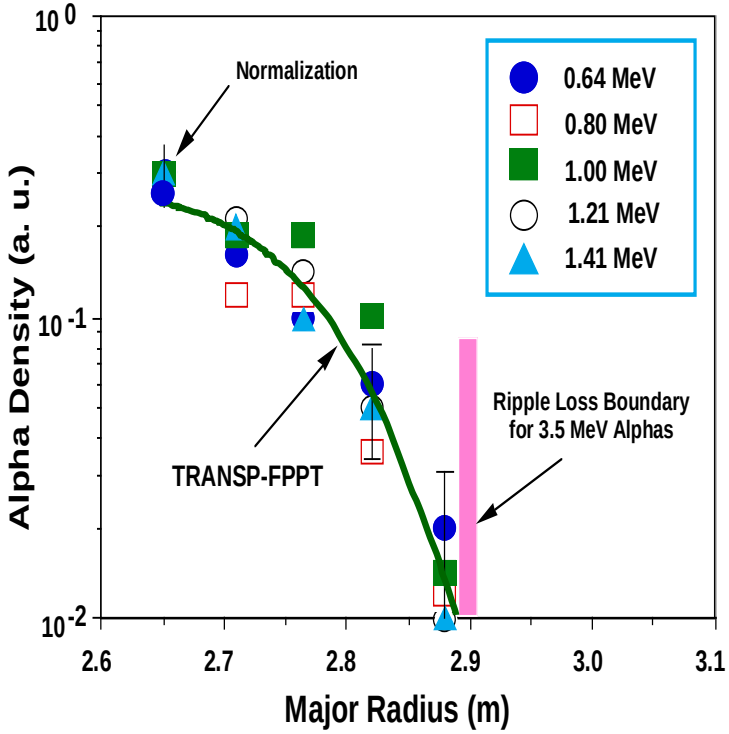
- **Vertical Scattering**
- **Source Laser**
  - CO_2, 10.6 microns
  - 15 Joules
  - 1 microsecond
  - 0.5 Hz - 5 pulses/discharge
- **Receiver**
  - Local oscillator - CO_2, 10.6 microns
  - Quantum Well Infrared Photodetector (QWIP)
  - 8 GHz bandwidth - set by electronics
  - Marginal Noise, needs further reduction
- **Notch Filter**
  - Attenuation – 200,000 at the laser wavelength
  - Attenuation < 0.5 for Doppler shifts > 0.5 GHz

Upgrade Required for a Burning Plasma Experiment/JET-EP

- **Tangential Scattering**
- **Source Laser**
  - CO_2, 10.6 microns
  - 50 Joules
  - 1 microsecond
  - 10 Hz
- **Receiver**
  - Local oscillator - CO_2, 10.6 microns
  - Quantum Well Infrared Photodetector (QWIP)
  - 20 GHz bandwidth - set by electronics
  - Low Noise
- **Notch Filter**
  - Attenuation – 200,000 at the laser wavelength
  - Attenuation < 0.5 for Doppler shifts > 0.5 GHz

Pellet Charge Exchange on JET would measure Radial Profile of Alpha Distribution





- dn^{2+}/dE (incident alphas) = $\frac{dn^0/dE \text{ (detected neutrals)}}{F_o^{\infty}(E)}$

- PCX measurement of the trapped alpha density profile in an MHD-quiescent supershot.
- Only the trapped alphas born inside the stochastic ripple boundary for E_α = 3.5 MeV are confined and can slow down to produce the measured profiles.

Possible US Proposal for Pellet Charge Exchange on JET

1. Impurity Pellet Injector

- MIT would build an impurity pellet injector (velocity ~ 1 km/s) based on the same reliable proven-technology injectors used on Alcator C-Mod and TFTR.

2. High energy Neutral Particle Analyzers

- JET has an existing NPA and proposes to add two additional vertically-viewing NPA's for passive alpha measurements. By installing the impurity pellet injector for PCX on a radial port in their field-of-view, these NPA's would provide up to 3 spatial points on the alpha radial profile.

- We also propose to install a horizontally-viewing NPA, possibly the Ioffe unit previously used on TFTR, on the same JET radial port with the impurity pellet injector. This is the same geometry used on TFTR, and would yield radial profiles of the alpha energy distribution

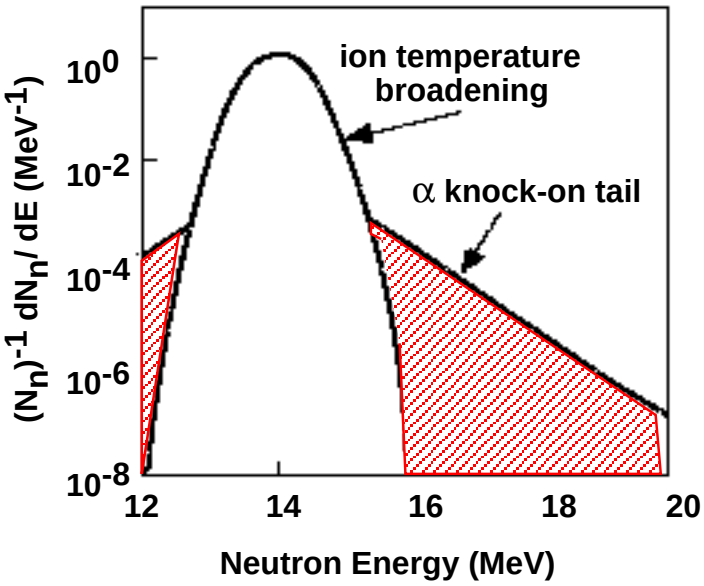
3. Diagnostic Modeling and Data Analysis

- US physicists, including R. Fisher and P. Parks from General Atomics, would participate in the modeling and data analysis with interested JET personnel.

Bubble-chamber Measurement of Alpha Knock-On Tails
Alpha Knock-On Tails Are Difficult to Measure

- **Small size (< 10^{-3})of knock-on tail requires detector insensitive to much larger flux of DT neutrons below 16 MeV**

- **First experimental observations of knock-on neutron tail were done on JET using Magnetic Proton Recoil Neutron Spectrometer (Kallne, *et. al.*); but it will be difficult to increase the MPR signal levels and gain additional information on the alphas**



- ***We propose to use single-gas bubble neutron detectors for measurements of the knock-on neutron tail***

- by increasing the number and/or size of the bubble detectors, we should be able to increase the signal levels to gain additional information on the alpha population and energy distribution which would complement the MPR information

Lithium Blanket Module

- **Proposal would be to provide an existing module to JET for measuring the local tritium breeding ratio:**
  - Obtain agreement between neutronics predictions and measurements
  - Estimate the nuclear heating deposition profile
  - Obtain local breeding ratio and extrapolate to next generation device
  - Evaluate effects of different Li compounds, neutron multipliers.

- **Engineering evaluation necessary with UKAEA and FZK.**

- **Propose neutronics analysis and preliminary testing with point neutron source with ENEA and FZK. Then install at a location close to the tokamak.**

- **If initial evaluation successful, develop a proposal for collaboration.**

Summary and Comments (1)

- **US Institutions have considerable experience in fabricating and using state-of-the-art diagnostics and supporting their use at off-site devices.**

- **Support of diagnostics for the JET-EP could be provided at three levels:**
  - Consultation in design and fabrication
  - Design, fabrication (and integration) of key components
  - Design, fabrication, installation and debugging of a complete system

Summary and Comments (2)

- **Definite statements of interest by US team members**
  - For operational support
    - Magnetic diagnostics ('halo' current, disruption modeling)
  - For turbulence and transport studies
    - High resolution Thomson scattering
    - "Improved" Motional Stark effect (MSE) system
    - Edge q(r) by lithium Zeeman spectroscopy
    - Correlation x-mode reflectometer
    - Edge reflectometer
  - For fast-ion and alpha-particle physics
    - Alfvén antennas
    - Escaping fast-ion array
    - Fast-ion collective Thomson scattering (CO_2 and μ-wave)
    - Pellet charge exchange of high-energy alphas
    - Bubble chambers for confined alpha measurement
  - Lithium blanket module
- **Expertise exists for other diagnostics**